Corrosion:
In the American Infrastructure

Source Jodi McKinney

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Abstract

The impact of corrosion on the United States economy amounts to more than $300 billion annually (>$1.8 trillion globally) and expected to rise significantly over the next decade given the current state of infrastructure in the nation as well as worldwide. Current materials used in construction get preference for their ease of availability and inexpensiveness, which is a consequence of large-scale adoption leading to production. The neglect of its inefficiency in the long term is costing a fortune to the economy; however, the future costs are avertable. Historically, the industry has been slow to adoption of technological solutions due to longer duration of returns versus cost of investment and replacement on a massive scale, which cut the immediate profits short. It is necessary to invest in the future. Adoption of better materials such as fiberglass-reinforced polymers, innovation in reinforced concrete and coating of structures will prove to be an investment for a strong and durable future.

ENGR 2196 document scenario: This design document proposes an engineering solution for the age-old crisis of infrastructure degradation particularly focusing on corrosion in the United States. The proposal can be supported by the U.S Department of Transportation Federal Highway Administration's (FHWA) Office of Infrastructure, for regulation and countrywide implementation to lower impact on the American economy. This future investment would pave way for advancement in the country's infrastructure and provide a long-lasting solution.

Executive Summary

The state of infrastructure in the United States saw its peak post World War II; often referred to as the Golden Age of Capitalism. However, the recession of 1970s also brought along an unending downfall in the American infrastructure. The results of failing infrastructure include but are not limited to job losses, business unreliability and increased costs leading to price inflation. Altogether, they put an enormous strain on the economy of the nation thereby affecting the GDP and lowering the quality of life. A significant number of bridges and roads in the United States are ineligible for use and even more need repairs for functioning, these structures pose great risk in the future. Collapse of bridges in Washington (2013) and Minnesota (2007) that claimed multiple lives paint a concerning picture of the structures responsible daily for the lives of millions of Americans.

The transportation infrastructure has been underfunded for a very long time now, which has led to deterioration of bridges across the country. The major cause is corrosion of metals in these structures. Rise of the industrial revolution saw a widespread use of iron and steel in western infrastructure. Iron is a pure element while steel is an alloy of iron and other elements, and both of them are prone to corrosion. It occurs due to long exposure to external environmental conditions, reaction, and breakdown when in presence of moisture (oxygen) known as oxidation[1]. While the widespread use of steel and iron cannot be ceased, a solution to this issue costing the American economy billions of dollars every year is corrosion prevention by coating of suitable materials. Rather than having to replace these structures, a cheaper, efficient and faster method would be coating of the structures with corrosion resistive electro-chemicals or wrapping of the structures in sheets made of reinforced polymers. Polymers have the advantage of being suitable for both concrete as well as metallic structures and can solve the problem facing transportation infrastructure overall which is mostly comprised of bridges made of steel and concrete roadways.

The adoption of these techniques to extend lives of current structures would prove beneficial in many ways. Rather than investing in newer projects, repairs done in the existing structures would lower the financial strain put on the economy, and pave way for the country's growth as an economy and pull up the quality of life in America.

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[1] See Glossary for definition

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Problem Statement

This section will highlight the state of the underfunded American infrastructure and the impact it has had on the country. The following sections will further investigate the causes due to administrative negligence and its effects on the transportation infrastructure, now and in the future. We will look at solutions that can avert future crisis and direct the economy towards a prosperous future. Of the candidate solutions, the best solution will be chosen that is most beneficial for implementation nationwide for betterment our infrastructure.

Initial Problem Description

The 607,380 bridges in the United States and thousands of miles of congested roadways in the United States need repair (The Real Truth, 2016). The problem seems to have begun following the recession in the 70s leading to underfunding of infrastructure projects. This underfunding, consequential neglect and lack of legislation has led to the deterioration of bridges and roads around the country. Most bridges built during the economic boom post the World War were designed with 50-60 year lives and that clock is soon going to stop ticking (NACE 2012). It is forecasted that this failing infrastructure will cost the businesses an amount up to $1.2 trillion while also putting the households under a $611 billion deficit. Crumbling infrastructure will also cost the economy close to 900,000 jobs (J. Dennison, 2013). The transportation infrastructure today stands at an overall grade of D+, which is a result of crumbling concrete and corroded steel. An investment of at least $4.59 trillion is needed to pull the grade up to a decent B (CNBC, 2017). While 14% of the bridges are now functionally obsolete, more than 70,000 are structurally deficient (S. Kroft, 2013).

The clock has been ticking, bridge collapses have occurred and it is only a matter of time for future disasters to take place unless curative measures are implemented. These include utilization of techniques such as coating with fiber-reinforced polymers. The corrosion preventive methods can be applicable for concrete as well as steel structures thereby proving effective for bridges and roadways at once. These measures involve the wrapping of concrete and steel in reinforced polymers thereby increasing the life by decreasing the rate of corrosion significantly also increasing the strength allowing higher load-carrying capacity (C. Lee et al., 2000). An incorporation of this method and support from lawmakers will help ensure American business and quality of living.

Overall Analysis and Objectives

The worsening condition of bridges and roadways in America is resulting in job cuts, business losses and daily inconvenience to the citizens. Corrosion is one of the biggest reasons for this issue, which has risen due to negligence, and underfunding of projects. The infrastructure is in dire need of repair and a curative measure is coating of corrosion preventive material on existing bridges to extend their lives and better their capacity.

Demolition and construction of new, more advanced and stable structures will be more expensive and requires time. Whereas, implementation of corrosion preventive methods would prove to be cheaper, less time-consuming and require fewer clearances from the government. As of now, the transportation-infrastructure budget remains 54% underfunded with only $941 billion in funding (ASCE, 2016). The economy faces a cost of $4 trillion in GDP and as many as 2.5 million jobs if the funding gap is unaddressed, by the year 2025 (ASCE). To prevent the wages to drop lower and save the disposable income flowing out from households due to failing infrastructure, it is important to address the issue and start with preventing the existing structures from further corrosion.

Corrosion prevention is possible by coating the structures with corrosion preventive materials. Corrosion is a result of reaction with the oxygen (moisture) present in the air or other elements in the atmosphere that result in oxidation of metals and cause it to break down. An approach to this is coating them with materials that do not undergo reactions with their external environment and at the same time shield the material inside. To prove beneficial, they must be cost efficient, increase the structures overall strength and its shelf life while causing least inconvenience to surrounding processes during the transition process. Given the urgency and current state of funding, the overall analysis suggests that repair is more practical, less time consuming and needed more than replacement. This repair can be brought about by coating with non-metallic substances using fiber-reinforced polymer. We will discuss the merits of this coating technique in the next few sections that will help provide the best results for transportation infrastructure in transportation.

TABLE 1 ★ **Losses to the National Economy Due to Infrastructure Investment Gaps**

(All values are in billions of constant 2015 dollars)[4,5,6,7]

	Surface Transportation	Water / Wastewater	Electricity	Airports	Inland Waterways & Marine Ports	Aggregate Economic Impact of All Sectors
Business Sales						
2016–2025	$2,212	$896	$1,399	$625	$1,252	$7,038
2026–2040	$8,152	$5,907	$2,024	$2,397	$4,239	$29,292
GDP						
2016–2025	$1,167	$508	$819	$337	$784	$3,955
2026–2040	$1,981	$3,215	$1,071	$1,073	$2,003	$14,201
Jobs						
2025	1,052,000	489,000	102,000	257,000	440,000	2,546,000
2040	473,000	956,000	242,000	494,000	1,153,000	5,809,000
Investment Funding Gap—2016 through 2025						
Total Needs	$2,042	$150	$934	$157	$37	$3,320
Funded	$941	$45	$757	$115	$22	$1,880
Funding Gap	$1,101	$105	$177	$42	$15	$1,440
Investment Funding Gap—2016 through 2040						
Total Needs	$7,646	$204	$2,458	$376	$112	$10,796
Funded	$3,312	$52	$1,893	$288	$69	$5,614
Funding Gap	$4,334	$152	$565	$88	$43	$5,182

NOTE The total economic impacts caused by the gap are listed by sector. Note that the economic impacts are based on each specific sector and the research and modeling by sector developed in the initial *Failure To Act* reports and adjusted based on the gap from 2016–2040. As these impacts do not related to the investment gaps across infrastructure systems is not totaled. However, projected cumulative economic effects of the gaps in all sectors are presented in the aggregate section. All year totals in constant 2015 value. However, job totals are a single year impacts for 2025, not cumulative totals.

Figure 1 Cost of Failing Infrastructure (Source: ASCE)

Historical and Economic Perspectives

There was an economic boom post the Second World War and the infrastructure sector witnessed heavy investment, which lasted until the recession of 1970. Since then, investment in infrastructure has only seen a decline and negligence from lawmakers. As of 2016, the spending on infrastructure has hit rock bottom reaching a 30-year low per The Fiscal Times.

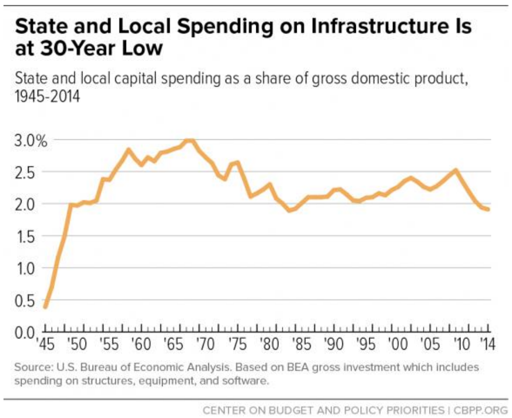
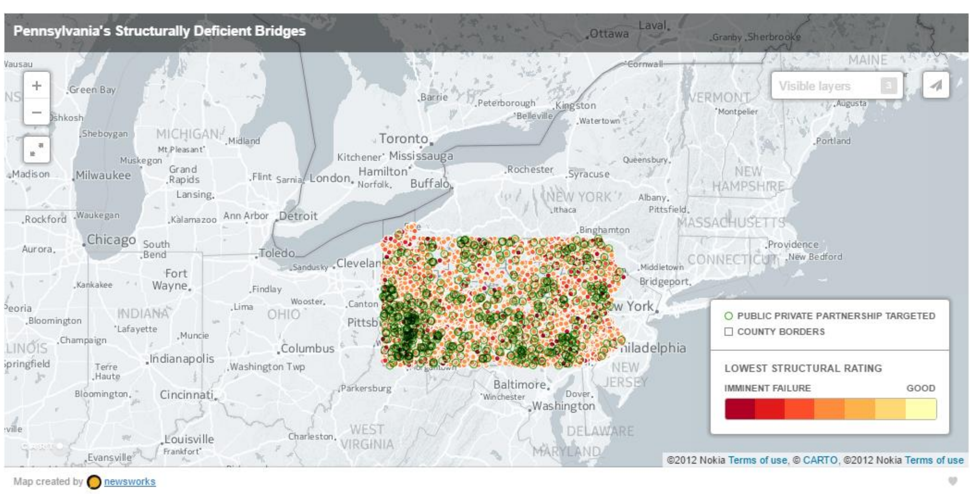


Figure 2 Infrastructure spending at 30-year old low Source: The Fiscal Times

The conditions for the north eastern states are even worse due to severe winters, which require frequent showering of salt responsible for corrosion and erosion of the bridges and byways. In the state of Pennsylvania alone, 300 bridges fall in the category of structurally deficient yearly accorading to Andy Herrmann, former president of ASCE. A map based on data from PennDOT on structurally deficient bridges in Pennsylvania is shown in Figure 3.

According the Amtrak's former president Joe Boardman, there is no dearth of remedies in the government on both sides however it is difficult to arrange for the funding. A Senate Leader from New Jersey, Loretta Weinberg, acknowledges the governments failure to act upon the sorry state of the transportation infrastructure and went on record to say, "In Jew Jersey, our bridges aren't old; they're mature. Unfortunately, our response to this fact has been immature."

Figure 3 DATA Source PennDOT, Todd Vachon, 2014



Candidate Solutions

Protective Coatings

Methods like Barrier Coating, Galvanizing and Metallizing can prevent corrosion against deicers on highways and bridges (NACE 2012).

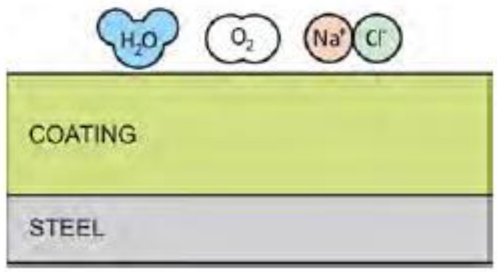


Figure 4 Barrier Coating (Source: NACE)

These coatings are applied on the outer surface of structures and work against the corrosive elements to prevent from reaching the inner steel surface. The rusting of the iron in this steel results in formation of iron oxides, which occupy an area larger than the steel bars leading to cracking and further breaking of the concrete (NACE 2012). **Primers**[2] can provide a life of up to 30 years to steel structures (Kline 2008). Common primer today is zinc-rich primers that include zinc metal however; these primers are themselves not resistant to the atmosphere and environmental elements surrounding the structures. Although they are corrosion preventive, they need an extra layer of coating.

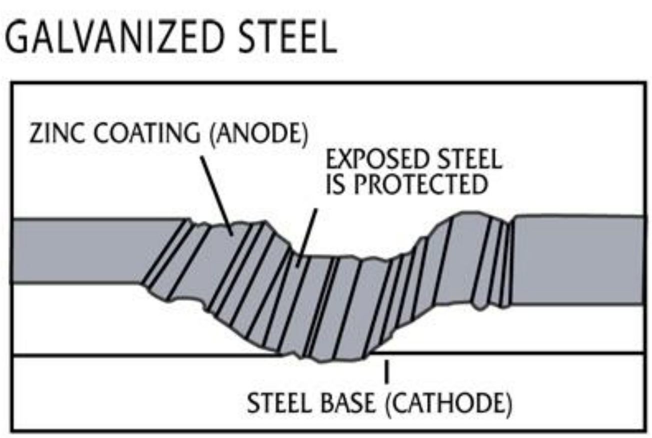


Figure 5 Galvanizing (Source: Moore Galvanizing)

Galvanizing[2] is the process of applying a layer of zinc metal over the surface of steel. The zinc is exposed to environmental conditions; it reacts and undergoes corrosion while the steel structure under it stays safe. Here, the zinc acts as a sacrificial anode. The most common method of galvanization is the hot-dip process (HDG) which involves the dipping of steel in a pool of molten zinc. Because corrosion of the zinc metal still takes place over the surface, it needs to be cleaned from time to time (NACE 2012).

Metallizing[2] is the spraying of molten metals or ceramics, which is corrosion resistive on steel structures. Spraying a molten state provides the benefit of sealing hard to reach spaces as well.

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2 See Glossary for definition

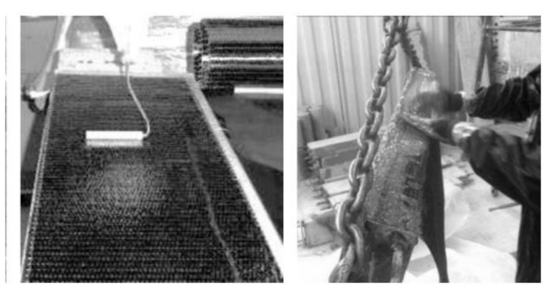
It is popular among the U.S. Navy and is preferred over other coating methods for their vessels (NACE 2012).

	Galvanizing
Adhesion	Several Kpsi
Application	Works only on prepared surfaces
Bond to steel	Excellent
Curing	None required
Maintenance	Little, if any
Transportation	Resistant to Abrasion
Availability	365 days a year

Table 1 Galvanizing Facts (Source: Moore Galvanizing)

Fiber Reinforcement Polymer Coating

While metal coating still leads to corrosion of the outer surface, an alternative is FRP or fiber reinforcement polymer. In this technique, the structure or material that is to be prevented from corrosion needs to be wrapped around with sheets of FRP. This easily adds about 30 to 40 years of live to concrete structures. Carbon fiber can be used resulting in carbon fiber reinforcements that can not only provide corrosion resistant but do not undergo rusting themselves. They protect the steel and themselves from weather conditions and external environmental conditions affecting the material. Additionally, they help increase the overall load-capacity of the structure they are wrapped in them.



CFRP sheet bonding CFRP sheet wrapping

Figure 6 CFRP (Carbon Fiber Reinforced Polymer) Source: Scielo.br

Proposed Solution

Using Carbon Fiber Reinforced Polymer (CFRP) stands out as a solution fitting the criteria for the most effective method. Primers provide protection against corrosion but themselves undergo decay due to unfavorable weather conditions or exposure to water, soil (Corrosion Control Plan for Bridges, 2012). Similarly, galvanizing can protect the steel under it but it is corroded over time and the corrosion of steel is imminent unless another layer is applied in time. Metallizing is another good option but unlike all candidate solutions, wrapping in CFRP's not only prevents corrosion but also helps in strengthening the overall structure.

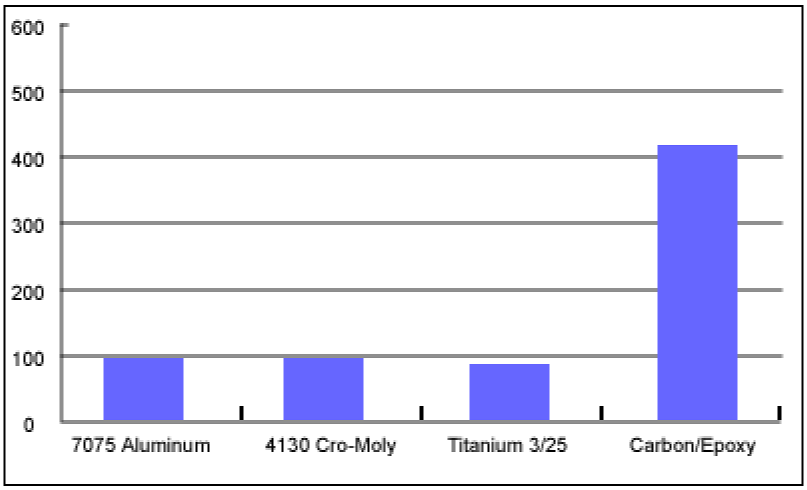


Figure 7 Stiffness to Weight Ratio (Tension) Source: Calfee Design

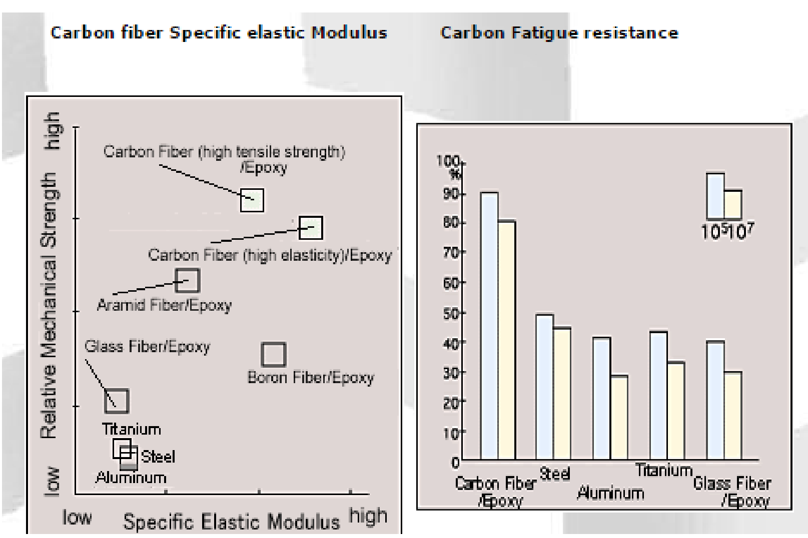


Figure 8 Carbon Fiber Comparison (Source: Formula1-Dictionary)

CFRP has many benefits including corrosion protection, increased load-carrying capacity and ductility (C. Lee et al., 2000). An already corroded structure can show an increase of load-capacity up to 28%, while also decreasing the rate of corrosion down to half by 50%. This advantage owes to the presence of carbon fiber in the polymer. They are very stiff, sometimes as stiff as steel, highly durable, and lightweight (Burgoyne, 2009).

On a broader scale, fiber reinforced polymers also provide protection against a range of chemical pollutants (Singh, 2015). Providing protection against gasoline on highways is highly beneficial to the highways across the United States. Wrapping of the reinforced polymers bonds with the reinforced concrete structures, which brings down the osmosis[3] and diffusion[3] process that could take place in unsuitable environments. They have a higher tensile strength as well as fatigue resistance compared to popular corrosion resistive material such glass fiber, aluminum as show in Figure 8.

The process would be identification of the structure in need of repair, prioritizing from critical to functional and then design of plan for individual structures to wrap all the surfaces of the concrete and steel structure exposed to corrosion.

Figure 9 Plan in Action (Source: Schnell Contractors)

3 See Glossary for definition

Major Design and Implementation Challenges

While it is one of the better and most relevant option out there, CFRP is still not the best. Many areas need improvement. Not everyone (NACE 2012) agrees upon its effectiveness. Moreover, there is still a lot of scope for further research in this field. For example, although the bonds between the fiber and concrete prevent osmosis and diffusion of material, it is not long lasting and shows poor results. An additional nano-coating over the CFRP sheet is needed for prevention. This results in increased costs.

Research into the production of carbon fiber is necessary, as its production currently needs more energy than steel (Das, 2011). With the ongoing global warming crisis, this raises a huge concern for the carbon emissions and footprint related to infrastructure repairs throughout the country. It must be considered first and only the most critical projects must be given green lights before a greener method of carbon fiber production is developed.

Implementation on a countrywide level is also a huge issue. The current state of infrastructure requires transformation of the bridges and roadways across the country on a scale never seen before. Given the underfunding of transportation infrastructure already, it would still be difficult to pass legislation or approve special budgets for this method that is not yet widely agreed upon among the scientific community (NACE 2012). This lack of consensus could further result in weak support from political communities.

Implications of Project Success

If CFRP wrapping were successful, it would prevent corrosion of concrete and steel bridges. This will lengthen the lives of existing structures, prevent future collapses saving many lives and reduce losses incurred by businesses.

Would it not only have great economic benefit but also make daily travel more convenient and better the quality of life for millions of Americans. Adoption of this technique for repairing structures will generate more interest in the research community and cheaper and faster ways can be developed achieving even better results. This would solve the problem of crumbling infrastructure around the country, bringing up its grade and thereby improving American infrastructures' rank around the globe

Glossary[4]

Oxidation: combine or become combined chemically with oxygen.

Primer: A primer or undercoat is a preparatory coating put on materials before painting. Priming ensures better adhesion of paint to the surface, increases paint durability, and provides additional protection for the material being painted.

Galvanizing: Galvanization is the process of applying a protective zinc coating to steel or iron, to prevent rusting.

Metallizing: Metallizing is the general name for the technique of coating metal on the surface of objects.

Osmosis: Osmosis is the spontaneous net movement of solvent molecules through a semi-permeable membrane into a region of higher solute concentration, in the direction that tends to equalize the solute concentrations on the two sides.

Diffusion: Diffusion is the net movement of molecules or atoms from a region of high concentration (or high chemical potential) to a region of low concentration (or low chemical potential).

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4 All sources from Wikipedia

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